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2011 Status of the Automatic Alignment System for the National Ignition Facility

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2011 Status of the Automatic Alignment System for the National Ignition Facility*

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ABSTRACT

Automated alignment for the National Ignition Facility (NIF) is accomplished using a large-scale parallel control system that directs 192 laser beams along the 300-m optical path. The beams are then focused down to a 50-micron spot in the middle of the target chamber. The entire process is completed in less than 50 minutes. The alignment system commands 9,000 stepping motors for highly accurate adjustment of mirrors and other optics. 41 control loops per beamline perform parallel processing services running on a LINUX cluster to analyze high-resolution images of the beams and their references. This paper describes the status the NIF automatic alignment system and the challenges encountered as NIF development has transitioned from building the laser, to becoming a research project supporting a 24 hour, 7 day laser facility. NIF is now a continuously operated system where performance monitoring is increasingly more critical for operation, maintenance, and commissioning tasks. Equipment wear and the effects of high energy neutrons from fusion experiments are issues which alter alignment efficiency and accuracy. New sensors needing automatic alignment assistance are common. System modifications to improve efficiency and accuracy are prevalent. Handling these evolving alignment and maintenance needs while minimizing the impact on NIF experiment schedule is expected to be an on-going challenge for the planned 30 year operational life of NIF.

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Introduction

The National Ignition Facility (NIF) is the world's largest laser, designed to create fusion ignition and energy gain in a laboratory setting. The facility (Fig. 1) was completed February 2009. It consists of 192 (40 × 40) square cm beams arranged in four clusters (Fig. 2), each comprising six bundles of two-by-four beams, which are focused into a 10m diameter target chamber (Fig. 3). It is a conventional flashlamp-pumped neodymium-doped phosphate-glass laser of unique four-pass amplifier design for a laser of this size. Each square 1053nm beam is multipass amplified through 16 810mm × 460mm × 41mm laser slabs (125 metric tons for all NIF), transported to the target chamber through beam tubes and five mirrors, frequency converted to 351 nm, and focused on the target to within 50 microns. The system is housed in a building 150m long by 90m wide, standing 40m from the deepest point to the ceiling. An excellent description of the NIF architecture is provided in [1], and more description of the evolution and architecture is presented in [2].

On 10 March, 2009, NIF demonstrated a milestone performance of 1.1MJ of 351nm light to target chamber center. Target experiments commenced in May 2009. To date, NIF is continuing a series of target design tuning shots to be followed by ignition and gain experiments planned for the latter half of 2011. To meet this ambitious experimental plan, operational speed and reliability must be maximized while continuing to support the ongoing development tasks. This paper discusses some of the measureable aspects of reliability and alignment reliability improvements implemented, as well as the projected alignment development schedule.

As the world's largest optical instrument, NIF is a monumental achievement in its design, construction, commissioning, and transition to routine and safe operations. Alignment in particular was very challenging due to size, access limitations, and the sheer quantity of components. The Main Laser section is 47 m long (Fig. 2), followed by a 60m transport spatial filter, then an additional 80 m beam transport to the target chamber center.

The laser cavity and transport sections are suspended 4.6 and 7 m above floor level in the laser bay, and as much as 29 m above floor level in the switchyards. Over 40 large (>400mm square) optics and 35 small optics per beam line are positioned and aligned. There are a total of 14,000 optics, 7,500 Mirror surface actuators and 1000 cameras used to align the laser as part of normal shot operations [3] [4]. Current automated alignment operations are carried out in approximately 50 minutes.

Four beams at a time enter the chamber through a large, rectangular, final optics system (Fig. 3). They include optics for frequency conversion, phase-plate beam conditioning, a vacuum barrier, focus lens, diagnostics, and debris protection.

Measured progress in reliability

The ongoing responsibility of the system is to maximize the operational availability of laser for experiments. Significant goals have been met in both alignment speed and the reliability. Improvements in reliability were measured (Fig. 4 and Fig. 5) and were accomplished by the following actions: operator training, extensive emulated testing, hardware preventative maintenance, software upgrades for improved error handling, and increased automation.

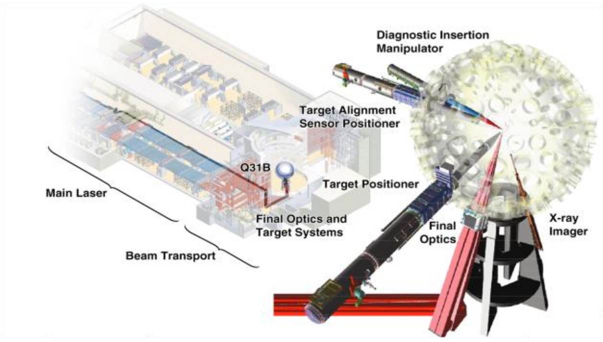

Fig. 1. The NIF building is approximately 150m×90m and seven stories tall. It has 192 separate laser beams that can be aimed at targets mounted on the target alignment positioner. Throughout the facility there are 14,000 manual and remote controlled mirror surfaces. To adjust mirrors, there are 7,500 mirror surface actuators. In addition, there are 3,500 stepper motors for non-mirror surface actuators, 2,200 binary actuators, and 1000 cameras. Using the noted devices, the automatic alignment of 192 lasers is typically done in 50 minutes.

Fig. 2. Photograph of laser-bay 2 from view bridge. 96 of the total 192 laser beams are in this laser bay. The beam tubes shown in the middle of image are the top of 4 sets. There are 16 automated alignment control loops that make optical adjustments in the main laser.

Many alignment tasks are on the critical path of shot operations, and as such, the reliability of automatic alignment operation can directly affect operational speed. All issues requiring operators to manually correct off-normal events result in a significant slowdown of shot operations. Automated systems work on several control loops in parallel, reducing personnel requirements to a single operator to address any off normal condition.

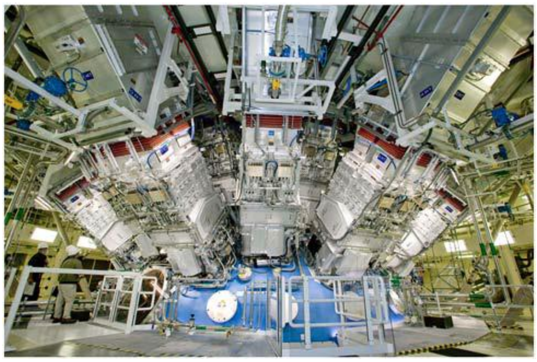

Fig. 3. Upper hemisphere of the 10m diameter target chamber. Each final optics system mounted on the side of the target chamber has 4 beams. Each beam has multiple optical systems.

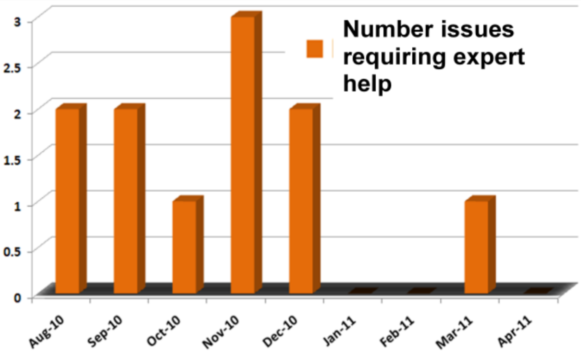

Fig. 4. Graph of number incidents resulting in stoppage of shot operations and consulting with experts to work around issues.

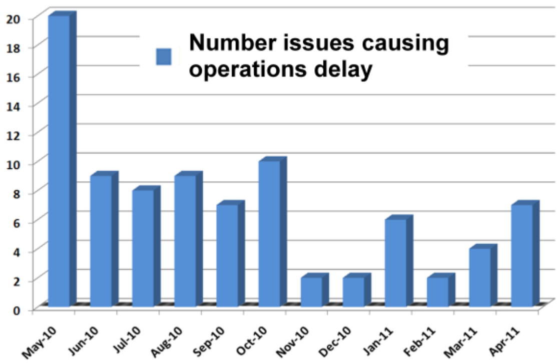

Fig. 5. Graph of incidents delaying shot operations as recorded in operational logs. There has been a recent minor increase in issues due to the commissioning of new systems.

Measured progress in alignment speed

In addition to the improved reliability of the laser, the alignment speed has measurably improved (Fig. 6 and Fig. 7). The speedup of automatic alignment was accomplished with software upgrades for better parallel operations, improved procedures to deal with hardware problems, operator training, hardware preventative maintenance, and increase automation.

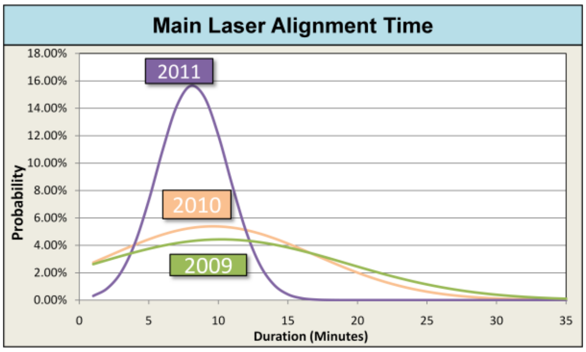

Fig. 6. The probability of completing alignment of a main laser section of a beamline during shot operations. This alignment time is approaching the mechanical limits of the device speeds.

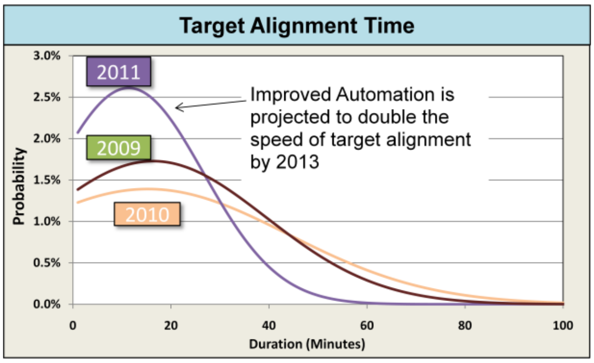

Fig . 7. The probability of completing the alignment of the target in the target chamber continues to improve as more automation is added to the alignment process

A large portion of the target alignment is still preformed manually. Since the alignment time of the target is significant and approximately equal to the alignment time for the rest of the laser, this area has become the dominant area for enhancement (Fig. 7).

The projected numbers of control loops show that the majority of the automatic alignment system is complete (Fig. 8). Initially, there were large increases in the number of control loops. This increase was mainly from replicated automation 192 times for each beamline. The replication of control loops was in the main laser, beam transport or final optics which represents the majority of the NIF automatic alignment system.

Alignment automation development is projected to continue as the planned systems are installed and upgraded (Fig. 9). Now that the conversion from Ada based control loops to Java based control loops is complete, the main area of development is in target area of NIF for target and diagnostic alignment.

Conclusion

The majority NIF automatic alignment system development is comlete and stable. Currently, there are refinement efforts focus predominantly on improving system availability through robustness improvements and modifications as a result of system upgrades.

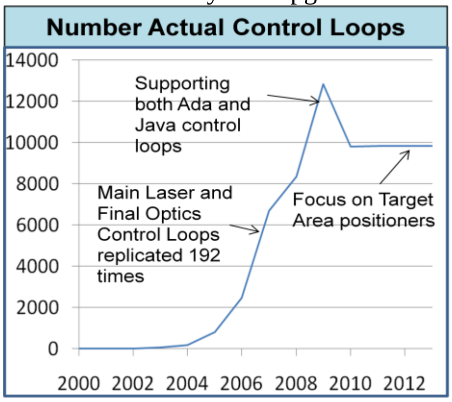

Fig. 8. The growth in control loops developed for NIF has leveled off. The roll off in the number of control loops during 2009 indicates the completion of the majority of NIF automatic alignment system. Control loops continue to be added, but projected increases are small.

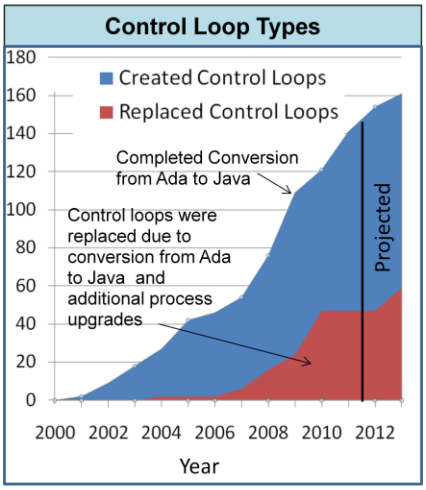

Fig. 9. The increase in control loop types illustrates the continuing development of specialty systems such as target area automatic alignment systems.

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